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Clean energy product markets in sub-Saharan Africa: Complex market devices and power asymmetries

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ABSTRACT

Low levels of access to modern energy services in sub-Saharan Africa combined with increasing awareness of climate change have made domestic-scale sustainable energy products, such as solar lanterns and improved efficiency cookstoves, popular within international development programmes. Following the turn towards private sector approaches to deliver basic services in the global South, many organisations of different types are trying to establish market infrastructure for these energy products to reach the 'consumers' they are designed for. This paper examines certain socio-technical arrangements within these market systems and identifies areas where they can inadvertently reinforce inequalities along the value chain, even if consumers are finally reached. Responding to Çalişkan and Callon's call for more research into marketisation processes and drawing on the concept of 'market devices', the paper identifies three market devices as case studies: warranties, carbon credit frameworks and product standardisation tools with related certification schemes. Discussion of these devices is informed by ethnographic research in Kenya, Uganda and Malawi.

1. Introduction

The years leading up to the current decade of 'Sustainable Energy for All' saw a rapid escalation of international efforts to provide access to modern energy services, with a Sustainable Development Goal (SDG) now dedicated to creating universal energy access. Numerous types of small solar products designed specifically around the needs of the poor have emerged. From 2011–2015, the known number of 'pico-solar' lighting products sold in sub-Saharan Africa grew from less than half a million to over 11 million, with unbranded products possibly doubling that figure [1]. Cookstoves have already had a long history within international development, with local potters since the 1980s being trained to produce stoves that provide increased fuel efficiency and reduced smoke emission compared to open 'three-stone' fires. These programmes are now being extended further and compete with hi-tech goods designed and tested in dedicated western laboratories. The proliferation has been driven by a combination of factors. The international development community, climate finance stakeholders, international and local businesses, and prospective end-users all engage with sustainable energy technologies for different reasons, making them multifaceted. As long as energy products are valued by different people or groups of people, they are open to market exchange.

How the markets around these products evolve has surprisingly had limited scrutiny, however. Going beyond a simplistic dichotomy of those with resources supplying and those in need buying, the nuanced character of an evolving market infrastructure can show very different levels of inclusiveness. Application of Çalişkan and Callon's [2] conceptual framework for markets as socio-technical assemblages helps identify that 'market devices' [3] can end up exacerbating inequalities between rich and poor. Complex mechanisms such as warranties, carbon credit frameworks and product standards are intended to protect or better serve the target market, yet their complexity can leave those in the target countries on the market peripheries, unable to gain value beyond the opportunity to be consumers.

This paper draws on examples from initial ethnographic research in 2011 and 2012 in Kenya, Uganda and Malawi, primarily participant observation of two British organisations (one charity and one social enterprise) working in the development of household-level solar and bioenergy product markets. A further 40 organisations were engaged with through interviews, and longitudinal observation of energy markets was continued through field research in 2014, 2015 and 2016, mainly in Malawi. The organisations and actors engaged with over time have included product designers and manufacturers, those developing profit and non-profit distribution channels in country, government agencies, carbon finance project developers and products standards organisations.

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2. Context: energy access for development

Given the strength of discourse and momentum around the energy poverty problem, the wealth of emerging 'pro-poor' and 'sustainable' energy products such as solar lanterns and improved efficiency cookstoves are often conceptualised as 'humanitarian goods' [4] or 'life technologies' [5]. Products aimed at meeting the needs of the 'energy poor' are also now situated within a landscape of increasing application of private sector approaches for achieving development aims. Advocated by Prahalad [6] and others, the turn towards market-based methods is based on the premise that stimulating domestic economic activity is conducive to development, whether it be through the poor as producers, distributors, consumers, or a combination of those roles within any given value chain. Organisations advertising a pro-development agenda have similarly broadened in their various guises – from traditional non-profit charities to specifically established 'social enterprises' or even mainstream multinationals (e.g. [7–9]).

This diversity is reflected in the emerging array of organisations trying to set up energy product supply chains in sub-Saharan African countries, predominantly targeted at off-grid rural consumers. Early efforts were often focussed on supporting the growth of small enterprises, an approach that has a long history within international development. More recently, the emergence of solar lanterns typifies a new wave of high-technology being specifically adapted to try and meet needs in developing countries. Basic solar lanterns are single light units with an integrated battery and either an integrated or detachable small solar panel (typically 0.5–5 W) and often with phone charging capacity. Larger units start to have more bulbs and a wider range of applications, such as being able to power a radio. Bringing the designs to those they are intended for are an increasing number of charities and companies variously involved in the design, mass manufacturing (predominantly in China), import and distribution of pico-solar products. Solar markets are often highly fragmented and vary significantly across sub-Saharan African countries according to local context and market maturity, amongst other factors. International suppliers and distributors can range from multinational companies introducing a new product line to specifically solar-focused, smaller international organisations. Local operators similarly vary in scale and degrees of formality. The majority of solar lantern producers and distributors engaged with during this research were small to medium sized international organisations, most being characterised as social enterprises.[1] They were found to be the most prevalent and active organisations on the ground in the three countries of research, with a particular focus on the Malawian solar market.

Social enterprises are similarly playing an increased role in a more commercially-focused cookstove sector. New international organisations[2] are designing and distributing highly engineered cookstoves that have the same basic components as the models that local potters have been trained to make since the 1980s [10], yet are visibly distinct due to their advanced design and mass manufacturing origins. The cutting edge designs provide greater fuel savings for the user, reduced smoke production and increased durability. The final products inevitably have a higher cost than more traditional stoves, but that does not always end up reflected in the consumer price and can create a tension where local stove production is already established. The two main types of cookstove producers engaged with during this research were again based on which market participants were found to be most active on the ground in the focus countries, particularly Kenya and Uganda. They therefore reflect the dichotomy outlined above: firstly, local individuals or small co-operatives of limited formality, producing stoves using traditional methods and often supported by international non-profit organisations, and secondly; small to medium sized international organisations producing hi-tech imported stoves and being the more recent market entrants.

3. Conceptual framework: the socio-technical nature of markets

Many early academic studies into renewable energy-oriented development interventions present case studies to demonstrate that the technologies applied are effective rural electrification solutions (e.g. [11,12]) or analyse the barriers to their take-up (e.g. [13,14]). More recent literature has provided some analysis of the challenges and advantages of using market-based approaches to provide access to these technologies (e.g. [15–18]).

This paper, by contrast, is underpinned by the premise that a growing emergence of commercial market-based approaches requires a similarly market-focused conceptual framework in order to reveal the dynamics of new actors and relationships in the energy access space. Detailed analysis of the specific processes occurring to actually create the market infrastructure for these products is required, in line with Çalişkan and Callon's [2] compelling argument for greater study of 'marketisation'. They apply the marketisation term to "…the entirety of efforts aimed at describing, analysing and making intelligible the shape, constitution and dynamics of a market socio-technical arrangement" [2, p. 3].

Callon et al. [3] identified that the actual tools and systems that allow markets to function (i.e. products and services to circulate) are often overlooked in social science studies. They term "the material and discursive assemblages that intervene in the construction of markets" [3, p. 2] as 'market devices,' similar to Foucault's 'dispositifs' (often translated as 'apparatus') but with physical artefacts and tools incorporated. Market devices help shape the ways in which people and products interact in a market, for example shaping the processes of qualification[3] and price setting.

In its journey from being an object of undefined value to becoming a product circulated in a market, there are numerous ways in which a sustainable energy product, like any other commodity, is stabilised in terms of its physical form, its conceptualisation and its associated value. These qualification processes often involve numerous market devices, from standardisation and quality frameworks that lead to consistent products and quality assurance labels, to packaging and marketing materials, to contracts for the longevity or replacement of the product through warranty schemes. Successful application of market devices can help increase the perceived value of a product for sellers and buyers. Callon et al. [3] cite examples of market devices "from analytical tools to pricing models, from purchase settings to merchandising tools, from trading protocols to aggregate indicators" [3, p. 2].

In order to understand the link between market devices and power asymmetries, exploring the complexity of tools applied in markets reveals how market systems are defined and dominated by expert discourse. As described by Foucault, expert discourse has a key role in maintaining power and control of societal institutions. Foucault focused on physical institutions such as prisons and mental health facilities; for example, he showed [19] that the expert medicalised discourse which now shapes madness is perpetuated by a network of healthcare professionals and their associated institutions, and can only able be countered with competing expert discourses. This gives experts in the field power to shape attitudes more widely and restrict other ways of thinking as a form of control. Similarly, the emergence and application of expert discourses in the design and operation of market systems gives control to those who shape and enact those discourses, leading to the perpetuation of power asymmetries.

Callon and Latour [20] use the term 'black box' to describe how

[1] For example: D.light design, Nokero, Greenlight Planet, Barefoot Power, BBOXX and SunnyMoney.

[2] Such as Envirofit and Burn Design Lab.

[3] Qualification: whereby the list of qualities attached to goods are repeatedly "attributed, stabilised, objectified and arranged" [39, p. 199].

actors gain power through expert discourses, technologies and practices. In *Unscrewing the Big Leviathan* they show that black boxes are a key part of the process by which macro-actors emerge in society. "A black box contains that which no longer needs to be reconsidered, those things whose contents have become a matter of indifference. The more elements one can place in black boxes – modes of thoughts, habits, forces and objects – the broader the construction one can raise" [20, p. 285]. In this way, the creation of black boxes is what allows micro-actors to gain power and grow into macro-actors. In *Science in Action* [21] the term is used as a reference to pieces of machinery or sets of commands that have become too complex to explain, resorting to a simple focus on what goes in and comes out (inputs and outputs) of the 'black box'. The double helix shape of deoxyribonucleic acid (DNA) and a computer developed to model the shape of DNA on a screen are given as examples. Both the 'fact' of DNA shape and the piece of electronic equipment that models it have long, complex and often controversial histories, yet they have become stabilised as cold 'black boxes' that are unproblematic.

MacKenzie [22] highlights how analytical techniques derived from science and technology studies show the importance of opening up normally opaque black boxes that have emerged in market systems: "to investigate the contents, normally hidden, of successful procedures and successful machines" [22, p. 34]. In his study of financial markets specifically, MacKenzie [23] illustrates the power of a market device: the Black-Scholes model, developed by the economists Black, Scholes and Merton, that through its widespread application with limited scrutiny, patterns of prices were in fact inadvertently shifted towards the model, unnoticed. This market device had become a powerful agent within financial markets through its evolution into an unchallenged black box.

Based on such works, Lovell and Smith [24] assert that "one of the major intellectual achievements of the last decade has been to open up the black box of the economy to scrutiny from disciplines other than economics" (p. 457). If complex market devices are conceptualised as black boxes, it is not necessarily economists who gain power from this but anyone or any organisation who can see inside and/or shape it; this gives them power over those that are excluded. Informed by ethnographic research into emerging domestic-scale energy product markets in East and Southern Africa, this paper identifies three market devices where inequality issues can arise from their application: warranties, carbon credit frameworks and product certifications.

4. Warranties for solar lanterns

Although a limited number of initiatives to encourage local artisanal production can be observed, the prominent model for solar lantern programmes in sub-Saharan Africa is now import of products designed in the US, Australia or Europe and primarily manufactured in China or India. Alongside the import of products, consumer-focused market devices such as warranty systems can also be seen being imported into rural African settings (see Fig. 1, showing the actors involved).

Part of the valuation process of a product involves considering the length of time for which it will be able to serve its intended purpose. Partly to give prospective consumers confidence that their new purchase will perform as advertised for a minimum duration, most solar lanterns and cookstoves imported by development intermediaries are distributed with warranty certificates. All of the products sold by the largest solar lantern distributor in Malawi, for example, are sold with a piece of paper or card in the packaging that describes an after-sales service promise from the absent manufacturer to the buyer. This is in the form of a list of legal terms and conditions of their mutual obligations, written in English. An example is shown in Fig. 2.

This card essentially establishes a contract between the end-user and manufacturer of the lantern. That manufacturer had no physical presence in Malawi at the time of research, however, except via the importer, and this card represents just one small piece of a larger market device. Only if this warranty certificate exists alongside the full human and material capacity needed to fulfil it, can it become more than simply a passive piece of card.

One of the first challenges to the successful operation of the warranty market device is that in order to validate a warranty, customers need to prove the date of purchase. Initially the primary Malawian importer provided their lantern sellers with receipt books for this purpose; a pad of specially marked papers with differently coloured carbon copies for each. However, since 2012 the cost and responsibility of providing receipts has lain with the sales people themselves. Operating with varying levels of formality, many have not continued this. At the time of research, increasing numbers of problematic products were being filtered back to the importer's main office without indication of whether they were still bound by the theoretical warranty contract. More recent observations indicate that this problem is still arising. If using a time-bound warranty becomes reliant on the end-user naming the purchase date without written record as evidence, the warranty becomes trust-based. This arguably negates the introduction a physical paper-printed warranty to formalise the agreement in the first place.

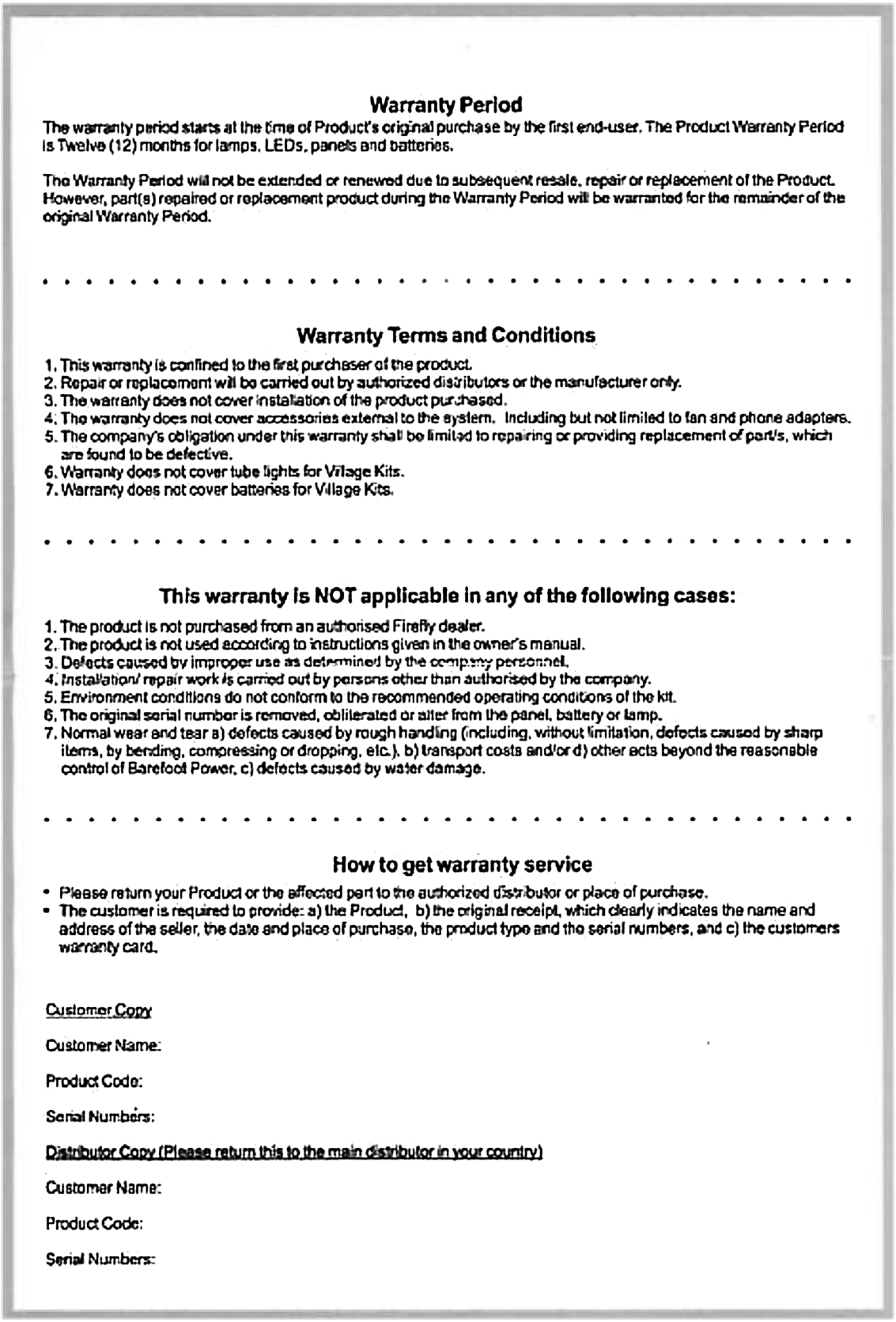
At the same time, the manufacturers whose products the Malawian importer distributes do not yet offer a service of providing replacement parts, only full replacement of faulty products once they are sent back. This common approach leaves independent importers stifled in their efforts to develop capacity to mend faulty products or equip the actors in their sales networks with spare parts. For the most vocal or significant customers, the easiest or sometimes only option for the importer is to provide them with a brand new replacement product. This depletes their stock during the time taken to inform the manufacturer and receive extra products in the next consignment sent to the country, usually up to six months later.

Other broken products stay with dissatisfied customers who are not aware of the rights that their warranty certificate apparently gives them. Even where a customer can read these promises written in English, they have no way of proving that the warranty period has not expired yet and limited ability to make a claim against the warranty for various reasons. Firstly there may be a long sales chain to go back through (see Fig. 1), often with extensive geographical distances between each actor that take significant time and money to deliver a product back across, with no available recompense; a solar lantern cannot simply be posted back to the shop in prepaid packaging.

Furthermore, in Malawi and its neighbouring countries there is often limited history of warranty systems, perhaps because of the predominance of informal market exchanges. Research in several trading posts in northern Malawi where solar lantern sellers are active found that few customers ever came back with a faulty product. If they did, the sellers' view was often that it was bad luck that the manufacturer had made a bad product and they had no responsibility to rectify the problem. Only if the customer was particularly troublesome might the seller occasionally choose to provide a replacement.

In many humanitarian goods markets, local distribution networks are established by recruiting and training local 'entrepreneurs' to become the valuable part of the supply chain, going the 'last mile' to reach

Fig. 1. Example of solar lantern sales chain along which warranty promise is made.



Warranty Period

The warranty period starts at the time of Product's original purchase by the first end-user. The Product Warranty Period is Twelve (12) months for lamps, LEDs, panels and batteries.

The Warranty Period will not be extended or renewed due to subsequent resale, repair or replacement of the Product. However, part(s) repaired or replacement product during the Warranty Period will be warranted for the remainder of the original Warranty Period.

Warranty Terms and Conditions

1. This warranty is confined to the first purchaser of the product.
2. Repair or replacement will be carried out by authorized distributors or the manufacturer only.
3. The warranty does not cover installation of the product purchased.
4. The warranty does not cover accessories external to the system. Including but not limited to fan and phone adapters.
5. The company's obligation under this warranty shall be limited to repairing or providing replacement of part/s, which are found to be defective.
6. Warranty does not cover tube lights for Village Kits.
7. Warranty does not cover batteries for Village Kits.

This warranty is NOT applicable in any of the following cases:

1. The product is not purchased from an authorised Firefly dealer.
2. The product is not used according to instructions given in the owner's manual.
3. Defects caused by improper use as determined by the company personnel.
4. Installation/ repair work is carried out by persons other than authorised by the company.
5. Environment conditions do not conform to the recommended operating conditions of the kit.
6. The original serial number is removed, obliterated or alter from the panel, battery or lamp.
7. Normal wear and tear a) defects caused by rough handling (including, without limitation, defects caused by sharp items, by bending, compressing or dropping, etc.), b) transport costs and/or d) other acts beyond the reasonable control of Barefoot Power, c) defects caused by water damage.

How to get warranty service

- Please return your Product or the affected part to the authorized distributor or place of purchase.
- The customer is required to provide: a) the Product, b) the original receipt, which clearly indicates the name and address of the seller, the date and place of purchase, the product type and the serial numbers, and c) the customers warranty card.

Customer Copy

Customer Name:

Product Code:

Serial Numbers:

Distributor Copy (Please return this to the main distributor in your country)

Customer Name:

Product Code:

Serial Numbers:

Fig. 2. Warranty card for solar lantern.

the target group. This is similarly an approach often used for selling solar lanterns to remote off-grid consumers. The local sales people engaged provide access to areas and people that would otherwise involve significant investment to reach. With many companies using this approach to open up 'bottom of the pyramid' markets there have been some insightful critiques, sometimes questioning the ethics behind

appropriating the social networks of the poor, or at least considering the potential impacts, both positive and negative, on them (e.g. [4,8,25,26].

High standards are being sought for energy products such as solar lanterns and this aims to reduce the incidence of product failure. However, they are complex electronic goods which are used in testing conditions so that occasional failures are inevitable, in addition to them having components such as batteries which require periodic replacement. Although the intention of providing a warranty is to smooth over such issues and provide a minimum longevity of product operation for the customer, if there is no means for the warranty to be enacted then it removes this safety net. Analysis of harnessing the poor's social networks to make product or service sales draws attention to how established trust between people facilitates each sale (e.g. [8]). When a solar entrepreneur sells a good to their friends, family or acquaintances that turns out to be faulty, with no avenue for redress, the loss of reputation can fall hardest on the customer-facing local sales people.

Warranty systems have been introduced partly to protect product purchasers, yet in the rural sub-Saharan African contexts observed they can be stifled by informal and remote sales networks, and limited opportunity for actors to know or fulfil their sides of optimistically worded contracts written in a language they may not speak. For manufacturers and suppliers the intention of warranty systems is to gain the trust of customers so that they and their networks are enticed to participate in the product market on a repeated basis. Without the system functioning, this value is not being gained and the market remains exposed to risks of reputational damage in the longer-term. This risk is evident from conversations with customers who have experienced unresolved solar lantern failures.

Also problematic is that manufacturers incorporate the anticipated cost of a warranty device into their price setting calculations; that value is rarely getting experienced by the end-users, however, and is unlikely to be considered in their own valuations. In essence, they are forced to pay for an aspect of the product that they cannot easily benefit from, creating a power asymmetry in favour of the manufacturer during the market exchange. Despite having paid both for a product that is expected to provide a service, and for a warranty system that should guarantee that service for a minimum period after purchase, when a fault occurs their supposed humanitarian good becomes useless, bereft of its ability to perform as such.

5. Carbon credit frameworks

Low-carbon energy products such as solar lanterns and improved cookstoves have not only been competing in a market for consumers, but also for 'carbon credits'. Under the UN's Clean Development Mechanism (CDM) and various voluntary carbon offsetting frameworks, it has been possible to sell theoretical reductions in greenhouse gas emissions as 'offsets' in the global carbon markets. This extra revenue stream was a particularly strong driver for renewed international interest in cookstove projects in the last ten years. Conversely, however, it also developed the potential to cause tensions between different market actors by significantly altering the price of products. Acting as a subsidy device is not necessarily an issue in itself, but where there has been unequal access to carbon credits for competing market actors, it has marginalised those who cannot access the subsidies.

'Carbon credits' are tradable certificates generated under specific policy mechanisms to promote increased investment in low carbon energy projects, amongst other project types, that otherwise might not be financially feasible. Although they have had declining prominence in recent years, there have historically been two main types of mechanism under which carbon credits can be generated by emission reduction projects in developing countries. The regulatory system known as the Clean Development Mechanism (CDM) is operated under the UN's Framework Convention on Climate Change (UNFCCC) and allows eligible projects to produce and sell 'certified emission reductions' (CERs). CERs are measured in tons of carbon dioxide equivalent (tCO_2e) and signify the volume of greenhouse gas emissions avoided through the project's activities. Buyers of the CERs in the past have primarily been developed countries that were required to reduce their greenhouse gas emissions under the Kyoto Protocol and were able to buy 'offsets' to constitute part of the reduction [27]. This led to carbon trading under the CDM becoming known as the compliance or regulatory market.

The compliance market suffered since the Kyoto Protocol expired in December 2012, thus taking away country-level demand for carbon credits. The EU, which drove the majority of demand for credits from the CDM, has continued to buy CERs from least developed countries [28] but this demand has slowed as offsetting limits are reached. The Paris agreements made in 2015 indicated that a future international emissions trading system will be developed[4] but details of its design are not yet known.

Although less significant now, the World Bank [29] estimated that the CDM leveraged around US$95 billion in clean energy investment between 2002 and 2008, compared to US$80 billion of non-carbon-finance-linked sustainable energy investment in developing countries over the same period, and just US$19 billion for climate change mitigation delivered through Official Development Assistance. The CDM has not been as widely used in Africa as in other continents, however. African projects only accounting for 3% of all CDM projects and originating just over 5% of all credits created by the mechanism [30], indicating that there have been barriers to its uptake in African countries.

The other mechanisms under which carbon credits can be generated and traded internationally are known as voluntary mechanisms. There is a wide variety of voluntary mechanisms that work on the basis of organisations and/or individuals wanting to offset their 'carbon footprints' and requiring a clearly structured way of doing so. Voluntary carbon trading mechanisms have been established by various organisations, such as a consortium of development intermediaries that created the Gold Standard system for carbon offsets [31]. By the end of 2014, the voluntary market had led to a cumulative $93 million of investment in African projects to reduce emissions, with clean cookstove projects being a significant recipient. In 2014, Kenya generated almost half of Africa's voluntary credits, followed by the Democratic Republic of the Congo and Uganda Ecoystem Marketplace, 2015.

Since they first emerged, the detailed processes of carbon finance mechanisms have been continually revised and new layers of complexity added over time. The intention is to make them more transparent and more accessible and thus inclusive, but various critics have found the opposite to be occurring. Gutierrez [32], for example, analysed systems for gaining carbon credits from carbon sequestration in forests and described how: "instead of unfolding and evolving into something different, it in-folds and becomes increasingly pervasive and convoluted" (p. 641) in a process she terms 'capital involution'. Gutierrez finds that "the resulting system excludes small-scale producers from the market and rewards mostly the few international agencies that validate the projects" (p. 640).

Detailed examination of the procedures utilised within carbon finance frameworks brings to light examples of 'black-boxes', to use Callon and Latour's [20] term. For example, in order to commoditise reductions in different greenhouse gases, a common benchmark of the estimated 100-year global warming potential (GWP) of carbon dioxide (CO_2) has become the reference point. All other greenhouse gases accepted within carbon offsetting frameworks are thus translated into the unit 'tonnes of CO_2 equivalent', or tCO_2e [33]. GWP is measured through a combination of measurements and models of atmospheric and terrestrial carbon exchanges and long-term climatic impacts of

[4] The Paris Agreement, the outcome of COP21 (the 21st Conference of the Parties to the UNFCCC) in December 2015, indicates that post-2020 there will be a UNFCCC-led mechanism to support mitigation and sustainable development, which will enable international transfers of emission reductions.

gases. Although there have been varied estimations of and revisions to the GWP of different greenhouse gases in relation to CO_2 over time, the particular figures that were published by the Intergovernmental Panel on Climate Change [34] when carbon finance systems emerged in the 1990s continue to be used. Already a black box has emerged which is rarely delved into, let alone contested, by anyone other than the experts that created it [35].

In order to calculate reductions made by a particular project, such as the deployment and utilisation of renewable energy technologies, the tCO_2e that would have been emitted under a hypothetical 'business as usual' baseline scenario must first be calculated. Then the lower level of greenhouse gas emissions produced through use of the cleaner technology is calculated; the number of 'offsets' generated is the difference between these two scenarios over time. As Bumpus [33] explains, the materiality of technologies being deployed and their local 'socionatural context' contribute greatly to whether the carbon reductions are able to be commoditised or not. The problem of measurement ends up selecting those project types that are easier to measure. This partly explains the relatively late recent entry of cookstove projects, for example, into the world of carbon finance. On the other hand, Bumpus also posits that the need to engage local stakeholders to help solve the problem of monitoring the use of cookstoves (crucial for verifying the generation of offsets) reduces some of the asymmetries in "power and bargaining positions between northern carbon capitalists and southern NGOs or groups in need of finance for their development projects" [33, p. 629].

A Clean Development Mechanism (CDM) Methodology is a registered document that sets out the full process that must be used in order to calculate saleable CERs under the UNFCCC's CDM. CDM Methodology AMS-II.G [36], for example, is used to estimate the volume of emission reductions from clean cookstove projects, as well as setting out other requirements such as how the achievement of reductions over time should be monitored. Version 5 of AMS-II.G became valid on the 7th December 2012 after its approval at the 70th meeting of the CDM Executive Board, held during the 18th COP in Doha. The first version of the same methodology was adopted in February 2008 but only one project was registered under it. Based in Nigeria, it is likely that the German partners in that project (the carbon consultancy *atmosfair* and the NGO *LHL*) were the prime developers of the original methodology, since this is how they commonly arise. Subsequent revisions were then made following requests from other project developers, looking to make the methodology more compatible and favourable for their own projects.

The key formula for estimating emission reductions using the AMS-II.G methodology is shown in Fig. 3 below. In summary, it states that the emission reductions generated in a year is equivalent to the volume of non-renewable biomass that each stove saves, multiplied by the emissions factor per unit of that biomass and the number of stoves in the project. In order to determine the savings of non-renewable biomass per stove, there is a choice of a further three different equations, each requiring some form of test procedure to be followed.[5] Even once the emission reductions have been estimated and the rest of the CDM project registration process completed, every two years similar tests must be carried out on a 'representative sample' of the stoves that have been sold, to ensure that they are performing as expected. This involves the development of random sampling methodologies, identification of and visits to customer households, and further complex test procedures. Even the most basic monitoring plans require receipts with customer contact details to be able to identify a sample to survey in the first place, and more advanced projects now use GPS technology for marking the location of each stove sold. As described by one company: "The stove serial number is photographed and linked up with Google Earth via GPS, for easy identification at the monitoring stage."

$$ER_y = B_{y,savings} \times f_{NRB,y} \times NCV_{biomass} \times EF_{projected_fossilfuel} \times N_{y,i}$$

ER_y = Emission reductions in year y (tCO_2e/yr)

$B_{y,savings}$ = Quantity of woody biomass that is saved in tonnes per device

$f_{NRB,y}$ = Fraction of woody biomass saved by the project activity in year y that can be established as non-renewable biomass using survey methods or government data or default country specific fraction of non-renewable woody biomass (fNRB) values available on the CDM website

$NCV_{biomass}$ = Net calorific value of the non-renewable woody biomass that is substituted (IPCC default for wood fuel, 0.015 TJ/tonne, wet basis)

$EF_{projected_fossilfuel}$ = Emission factor for the substitution of non-renewable woody biomass by similar consumers. Use a value of 81.6 t CO_2/TJ

$N_{y,i}$ = Number of project devices of type i operating in year y, determined as per paragraph 22 [of methodology document]

Fig. 3. Emission reductions calculation for a clean cookstoves project under CDM Methodology AMS-II.G [36].

The system of generating carbon credits, as described above, has clearly become highly complex and immersed in a 'black box' that, without expert knowledge and tools, is impenetrable. Despite the original intention of carbon finance being to support low carbon development in poorer countries, it has become inaccessible to many potential market participants in those countries. A British NGO supporting local producers of clean cookstoves in Kenya, Uganda and Tanzania is working with the types of small local businesses that should be prime targets for carbon finance. However, very few of the producers (e.g. two out of thirty interviewed in 2012) have heard of carbon credits. Even where they have, they are far from having the necessary expert knowledge to actually claim and sell carbon credits. Furthermore, they tend to manufacture and sell products in far too small quantities to be able to benefit from the carbon markets on their own. The transaction costs of registering a project, obtaining credits and organising their sale are high and need to be outweighed by the volume of credits obtained.

Costs have been another significant barrier to penetrating the carbon finance market device. Even for a large company such as the solar lantern manufacturer D.light, the costs are huge. Cross [37] states that: "The project registration process involving third party assessment, validation and certification is extremely expensive and bureaucratic, and it took d.light design 18 months at an estimated cost of US $500,000." (p. 382) However, those who can pay the transaction fees can benefit from a significant return on investment: "Over the first two years, the project stood to displace some 80,177 tons of CO_2. With each ton trading at an average price of US$15 between 2009 and 2010, d.light design was set to raise around US$1.2 million" [37, p. 383]. Those engaging in carbon finance also need awareness and ability to negotiate the risks involved, particularly given that the price of CERs reduced significantly after the Kyoto Protocol concluded in 2012. The price of voluntary credits has always been much lower than for CERs, and both transaction costs and price volatility have also been lower accordingly [38]. Understanding which scheme to engage with and how is a huge barrier, however.

Local sellers of imported solar lanterns may be excluded from carbon finance mechanisms due to the lantern manufacturers already having claimed credits for those products, as in the d.light example above. In principle, though, the benefit trickles down through the retail price of the lanterns being lowered by the extra income stream. Local artisans, who themselves manufacture and sell low carbon products such as clean cookstoves, are more likely to be fully excluded, however. Large international manufacturers tend to have either in-house or external access to the technical, cognitive and financial capacity to utilise complex and high cost subsidy mechanisms such as carbon finance, which in turn reduces their product prices. Local artisans cannot access the same complex and costly market devices. Even if their cookstoves

[5] The choices include a Kitchen Performance Test (KPT), Water Boiling Test (WBT) or Controlled Cooking Test (CCT) and it is stated that relevant national standards or international guidelines (e.g. as developed by the Partnership for Clean Indoor Air www.pciaonline.org/testing) must be adhered to.

are significantly cheaper to make, lack of access to a significant financial stream being tapped into by international suppliers can make them unable to compete on price with sophisticated imported products.

This concern often plays out in conversations between market actors involved with cookstove marketisation initiatives that have adopted different approaches. These debates are most easily observed on social media, such as the following example from the LinkedIn group site of the UN's Energy Access Practitioners Network.

Initial post, 26 April 2012: *We are about to roll out 1 million cook stoves in Africa, but need a good reliable and cheap source of these cook stoves, anyone have any ideas? They will be handed out for free, so cheaper the better.*

This post led to an extensive and heated debate, starting politely but showing increasing frustration over time. Extracts are provided below from two different objectors and some of the initial poster's general responses.

Objection, 27 April 2012: *I'm a little concerned about your offer of providing 1 million stoves for free. This will disrupt local manufacturers in Africa that produce energy-saving cookstoves, especially if the stoves given are imports, as local manufacturers do not have the capacity yet to produce that amount. Even if you are sourcing from local manufacturers, the market will be disrupted for future sales or other villages that may have heard of the "free" stoves, but did not benefit. […] This type of aid mentality really disrupts entrepreneurship in Africa.*

Response, 27 April 2012: *Local manufacturers have the same market as we will be entering, if anything they are already there and have access to the same knowledge as we do, if anything more knowledge of the local market etc. […] We will upset the market, but that is the market and the other manufactures will have to adapt to the this new competitor on the block.*

Response, 29 April 2012: *Hello all, I have been getting some interesting personal posts on development in Africa, they way we see it, is that is it is not some special market, but a potential new market […] We have a business plan that […] will benefit the customer and the environment they live and work in. The small producers will have a bad time, but they have also had enough time to scale up, but not done, we will be big players and employ more than 200 people, provide services and education, but in the end do business.*

Objection, 4 May 2012: *How is it a "business" model if you give it away for free??? And yes, Africa IS a special case, because not only is the market for cookstoves young, the whole idea of a market is young. […] With cookstoves, where there are only 10 s of thousands being sold every year, 1 million free ones completely overwhelms the market. […] and undercuts the new generation of African entrepreneurs trying to make it in private business. If you've raised donations and are looking to make a difference, figure out a way to use it to CREATE a market, not destroy one.*

The crux of this argument is that the initial poster was involved in an internationally-led project being developed by a macro-actor, most likely a suite of organisations together having the complex social and technical components required to be aware of and take advantage of carbon finance as a funding stream for a cookstove supply project. By comparison, the small local producers referred to do not typically have this awareness or access, for those reasons set out above.

In summary the scale, complexity and technical tools required to engage with carbon market devices make them inaccessible to most informal producers, resulting in further power asymmetries between different types of market actors. Carbon credits add to the complexity of valuation by attaching another, often silent and invisible, benefits to low carbon products. It is only visible to those that have been taught to see it and have the knowledge and tools available to obtain value from it: generally organisations which can already be considered as macro-actors who thus reinforce their position further.

6. Product standardisation and certification devices

When a product is made available for purchase in a market, a potential customer firstly must be able to recognise that it will, in general, fulfil a need. Beyond that, a purchase often depends on being able to identify the product's capabilities more exactly, in order to accurately evaluate it and make comparisons with other possible solutions that could fulfil the same need. The processes of product standardisation that allow this to happen are those which most directly fit Callon et al.'s [39] notion of qualification: whereby the qualities attached to goods become stabilised. The results are typically presented on product packaging and marketing materials: exacting claims about the nature and abilities of the goods inside, allowing them to be benchmarked against competitors' offerings. The extent to which the product's described attributions fare favourably or otherwise against other solutions of known prices allows the customer to start calculating an appropriate monetary value for this particular product.

At an exhibition in Nairobi for environmentally friendly technologies, a flyer lying on the table at the trade-stand of a Kenyan solar lantern seller advertises one of the lanterns they sell. As well as information on the materials the lantern is made from and its key electronic characteristics, such as Wattage and Voltage, the flyer provides very specific data about the light's likely performance in its intended setting. It describes:

- the intensity of the light it will give out, in lumens;
- the length of time the light can be operated for in different modes, in combination or otherwise with mobile phone charging; and
- the overall battery life, in months.

These characteristics are provided in both absolute and relative forms, firstly using standard metrics and then providing a comparator that may be more universally understood than scientific terms such as 'lumens': "The lantern's bright white light illuminates a room similarly to a 3–5 W CFL lamp, and provides 10 times more light than a kerosene lantern". Verbal descriptions are also given summarising the product's uses ("it can be hung to light a room, placed on a desk for reading or easily carried by hand as a torch") and drawing attention to a one-year warranty offered in case the lantern does not in fact meet the performance descriptions given. Similar information is also given on the packaging of the lighting kits themselves, brightly coloured boxes stacked up along the back edge of the table.

The professional appearance of the marketing material and the stacked boxes with the lanterns inside provide people browsing the trade stand at the Nairobi event with a certain confidence in the legitimacy of the claims made. The warranty description underpins that further, even if, as described above, it may not be as straightforward to enact as the simple sentence on the flyer and packaging suggests. There is also another set of statements provided as a 'guarantee' of product performance, however, albeit one which equally requires an element of trust in the legitimacy of the black boxes referred to. Under a small subheading 'Quality' at the bottom of the flyer, the following is written in small print:

- CE certification
- IEC 60598-1, IEC 60598-2-4 compliances
- IEC 613-1, IEC 61347-2, IEC 60825 compliances
- Country certifications for East & West Africa (SONCAP, PVoC)

The IEC codes provided are for product standards for 'luminaires', covering the "classification, marking, mechanical construction and electrical construction" of electric light sources operating from up to 1000 V electrical supply [40] and other technical aspects of electrical products more generally.

None of the performance values provided in advertising materials or product packaging are immediately obvious from looking at the product alone, nor are the devices intended to guarantee adherence to these and other internationally-agreed performance metrics easy to understand or tap into from a manufacturer's point of view. Establishing product

metrics requires a vast complex system of laboratory and field tests, data collection over time, numerous measuring and recording devices, calibration equipment, testing protocols, trained staff, and so forth. This is not just for the product itself but also for those it is being compared with. It immediately highlights why international NGOs in the solar lighting sector have found that locally assembled solar lighting kits are unable to compete with the imported products that have engaged with these complex systems, resulting in standardised, high quality lanterns that come complete with detailed evaluative information and demonstration of adherence to international quality requirements. If the process of getting a product designed to and tested against an IEC standard is delved into, the same type of black box appears as that described above for carbon credit frameworks.

The ability to standardise is heavily affected by access to measuring equipment or tools that are already made to standard sizes. In local artisan manufacturing, by comparison with advanced mechanised manufacturing, even basic tools needed for standardisation are not always available. Biomass briquettes, for example, are small clumps of organic waste material that are sold for burning in cookstoves instead of charcoal. Working with briquette makers in Kenya, it became apparent that the majority do not have weighing scales. Instead of selling by weight, they sell by container size: a plastic bag, small bucket or large bucket is as close as a buyer can get to buying an exact weight of fuel. These containers obviously vary between sellers, making it difficult to accurately compare the price being offered by different sellers. Equally for the individual briquettes, if they are made by manual or automated machines it is more likely that they will be produced in relatively consistent shapes and sizes. Where people are making them by hand due to lack of machinery, the shape and size will vary to a much greater extent and this will affect the burn time per briquette.

Even a weighing system that can be described as a simple market device involves a much broader assemblage of human and non-human components than perhaps first envisaged: it must be of an appropriate design and calibrated for accuracy; there must be a user with the necessary technique to use it in the correct way; a way of recording the weight for later reference is desirable, and so on. All of these characteristics must eventually come together in a particular configuration and at a precise moment of time for the act of weighing to be carried out. Further along the spectrum, more complex market devices for evaluating product properties can require an almost inexhaustible lists of materials, tools and techniques.

Over the last few years, there has been a big push for international development-focused organisations involved with cookstoves and/or solar lanterns to strive for achievement of high quality standards in the products they deal with, exemplified by the various IEC and other certifications described on the lantern flyer discussed above. Various initiatives such as Lighting Global and the Global Alliance for Clean Cookstoves have supported this further by developing more specific international standards, providing testing protocols, creating certification systems and making inventories of certified products publicly available. Given the difficulties outlined earlier in enacting consumer protection devices for energy access products, it is clearly a positive step to ensure that high quality products are being offered, with every effort made to ensure that they function as intended, for the full duration of their expected lifetime.

The complex market devices that must be engaged with to meet a product standard and benefit consumers, however, again provide a barrier to artisan producers and domestic manufacturers in countries such as Uganda or Malawi. By comparison, international companies with access to large laboratories, skilled technicians and financial resources are well placed to comply with international standards, which have been designed by and for such companies.

There are currently very few examples of solar lighting kits being assembled in African countries; organisations such as SolarAid which initially used this approach, subsequently had to change tact to imported products in order to cost-effectively reach the scale of market penetration they were aiming for. For the cookstove sector, which remains more divided between highly engineered imported stoves and locally made artisanal stoves, having to achieve product standards is a more likely and immediate concern. Larger wholesale buyers such as supermarkets often require any products stocked to meet the relevant national standard.

This is to be encouraged from a consumer point of view, but it becomes problematic if a national standard has not yet been created and more stringent international standards are looked to instead. For example, although briquette-makers have limited competition from international manufacturers, one producer in Kenya encountered a problem when a large-volume buyer of his briquettes asked him to obtain a Kenya Bureau of Standards (KEBS) standard: one has not yet been developed. He therefore had to subject his briquettes to the same tests required by the relevant South African standard. The briquettes failed, yet the test had imposed unrealistic expectations on the much less developed Kenyan briquette market. There were rumours that the Kenya Industrial Research and Development Institute was looking to develop a Kenyan standard, but no further information has been found.

For cookstoves, where a large part of the market share is now produced through large-scale fully automated manufacturing outside of the target countries, the testing standards are being developed even further and becoming increasingly inaccessible for local artisan cookstove makers. Colorado State University's Engines and Energy Conversion Lab, for example, is developing advanced durability testing with automated testing rigs as part of their product development. They are also working with the US-based Global Alliance for Clean Cookstoves to develop an associated testing protocol, in turn leading to a laboratory standard for rating cookstove durability [41]. The complex and extensive socio-technical arrangements needed for such market devices, however, makes them unavailable in many countries and inevitably leads to power asymmetries between local artisans and increasingly 'macro' market actors such as those involved in advanced cookstove design in US institutions, despite their apparently similar market roles.

To compound this further, the higher standards achieved and the fact that there is certification to these standards, makes it easier for those international organisations importing highly engineered cookstoves to tap into carbon finance related subsidies, and gain more per stove sold. This in turn can help offset the higher manufacturing and distribution costs to better compete with the locally manufactured offering, repeating the argument discussed above on the disruption of fragile local markets.

7. Developing appropriate solutions or alternatives

The intention here is not to suggest that standardisation and certification of quality is not merited in markets where local producers would be unable to compete. Instead it argues for increased consideration of the value-share available to in-country market actors. Those developing standards for products that specifically target the poor in sub-Saharan African countries, for example, may be able to take the capacities of local manufacturers further into account, or focus on putting the peripheral market infrastructure such as testing facilities in place. There are signs that market actors involved in sustainable energy product markets are trying to establish greater local manufacturing capacity that can compete with import-level quality and are making some progress in this regard. Burn Design Lab, for example, has established its manufacturing arm, Burn Manufacturing Company, in Kenya producing cookstoves which are more akin to those designed and imported by international companies [42]. For solar, Africa's first large-scale solar module manufacturing units have been established in Ghana and Kenya [43,44] and undertake all processes except fabrication of individual solar cells.

The specific example of the CDM may not continue to be relevant much longer. However, national-level schemes continually emerge,

international mechanisms such as the Green Climate Fund are being shaped, and new designs may be scoped out to fulfil the Paris agreement. Again, considerations should be made to ensure that the accessibility of these schemes is more equitable, and they do not become subsidy schemes for the elite. There are various positive examples of where the power asymmetries in carbon finance have been tackled and recommendations may emerge from studying these. An NGO originating from the US, for example, established an office in Uganda to set up and manage a Gold Standard carbon finance project on behalf of a local cookstove producer. Half of the income gained from credit sales is being invested back in to the local company, particularly to upgrade their manufacturing facilities. Although the remainder goes towards the NGO's administrative costs and to pay for external support from a for-profit carbon trading company, the local manufacturers receive at least some of the credit value that would have been unlikely to be able to access otherwise.

Another solution is the aggregation of projects under larger umbrella programmes, known as Programmes of Activities (PoAs). Another international NGO in Uganda has taken this approach by using donor funding to establish an Improved Cook Stoves for East Africa PoA under which local cookstove manufacturers and projects can acquire carbon credits, again without having to undertake the process themselves. As a member of their staff described, since a project can be registered to generate carbon credits for 21 years, this does give the advantage of longevity by comparison with direct aid from a donor that is likely to last 4 or 5 years at most.

For warranty systems, there are examples where the market device appears to work in rural African contexts; this is because efforts have been made to put the necessary associated market infrastructure in place. In Uganda, for example, one solar product manufacturer has a presence in country and at the time of research had 21 'service centres' in locations across the country that aimed to make the fulfilment of warranties more viable. This type of market infrastructure is costly to provide and upkeep, however.

In Malawi and other countries without a manufacturer presence or a dedicated infrastructure of multiple repair centres, there are undoubtedly solutions that could be explored instead of or to improve western-originating warranty systems. Market research with a Malawian solar lantern importer, for example, identified that people around the targeted sales areas who offer a radio or mobile phone repair service often already have the skillset, if not necessarily the required tools, to fix various faults that might occur in popular solar lantern models. If these people could be engaged by the solar lantern companies, trained, given access to the necessary equipment, and a financial arrangement[6] for repairs agreed, these skills could be put to great use.

8. Conclusions

Caliskan and Callon [2] have clearly established the case and conceptual framework for studying the range of socio-technical assemblages that evolve during marketisation processes. This paper has set out to do that for markets around low-carbon household-level energy products that are emerging in response to the persistently low levels of access to modern energy services in sub-Saharan Africa. By focusing on the concept of market devices it has aimed to reveal the complexity and unequal access levels of even apparently simple market tools.

There may be ways of addressing these asymmetries of marketisation. This could include increased consideration of how to make market devices more locally appropriate, and a broadening out of market-based development approaches so that they promote greater local access to the wide range of currently inaccessible market devices. If successful, reducing power asymmetries between different market actors and increasing the African value-share in humanitarian product supply chains can help to make the benefits they offer more market-wide.

[6] A financial arrangement could use the more commonly found model in rural sub-Saharan Africa of consumers paying directly for repairs and not inadvertently paying a warranty value embedded in a product, or, something more akin to becoming contracted by the importer/distributor to fulfil warranty repairs.

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